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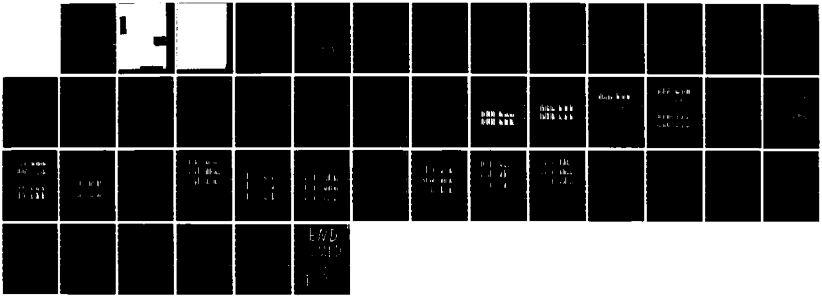

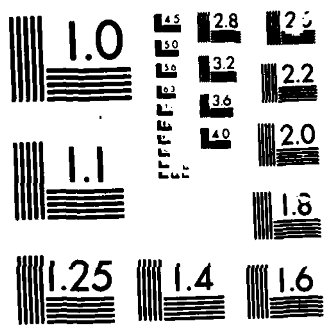

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Three years of field studies were conducted at Lake Texoma on the Texas-Oklahoma border to evaluate the suitability of selected plant species for use in reservoir shoreline revegetation projects. The plants were subjected to various inundation treatments and were monitored for survival and growth. Two field sites were established: one on the shoreline of Lake Texoma, the other in a nearby small impoundment where water levels were controlled by the researchers.

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20. ABSTRACT (Continued).

Of 16 species tested, 11 demonstrated sufficient flood tolerance to merit consideration in shoreline revegetation programs in the south-central United States. Two herbaceous species, *Arundo donax* and *Panicum virgatum*, appear to be well adapted to a range of inundation conditions, including up to 7 weeks of growing season flooding. Woody species were generally less successful than herbaceous species, but several, especially *Salix nigra*, demonstrated considerable inundation tolerance. Summarized experimental data presented in this report should facilitate planting programs by providing an indication of species tolerances of a range of potential inundation depth and duration conditions.

PREFACE

This report was prepared as part of the Environmental and Water Quality Operational Studies (EWQOS) Program, Task IIE.1, "The Environmental Effects of Fluctuating Reservoir Water Levels." The EWQOS Program is sponsored by the Office, Chief of Engineers (OCE), US Army, and is assigned to the US Army Engineer Waterways Experiment Station (WES), under the purview of the Environmental Laboratory (EL). The OCE Technical Monitors were Dr. John Bushman, Mr. Earl Eiker, and Mr. James L. Gottesman. Dr. Jerome L. Mahloch was the WES Program Manager of EWQOS.

The original concept for this research was developed by Mr. Hollis H. Allen of the Wetlands and Terrestrial Habitat Group (WTHG), Environmental Resources Division (ERD), EL. Fieldwork was directed by Dr. James E. Lester, Department of Biological Sciences, Southeastern Oklahoma State University, under Contract No. DACW56-79-C-0202. This report is based on annual research summaries assembled by Dr. Lester. Additional analyses were performed by Dr. Aubrey D. Magoun of Applied Research and Analysis, Inc., Tallulah, La. The field sites were established and maintained with the cooperation of Mr. Jeff London, US Army Engineer District, Tulsa, and Mr. Herb Smith, Lake Texoma Project Manager. The report was written by Dr. Lester and by Messrs. Charles V. Klimas, Hollis H. Allen, and Stephen G. Shetron, WTHG, EL. The report was edited by Ms. Jessica S. Ruff of the WES Publications and Graphic Arts Division.

The work was conducted under the direct supervision of Mr. Allen and Dr. Hanley K. Smith, Chief, WTHG, and under the general supervision of Dr. Conrad J. Kirby, Jr., Chief, ERD, and Dr. John Harrison, Chief, EL.

Director of WES was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
Fahrenheit degrees	5/9	Celsius degrees*
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
square miles	2.589998	square kilometres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$.

SHORELINE REVEGETATION STUDIES AT LAKE TEXOMA ON THE RED RIVER, TEXAS-OKLAHOMA

PART I: INTRODUCTION

Background

1. Denuded reservoir shorelines are often unsightly and erodible and are much less valuable as fish and wildlife habitat than vegetated shorelines. A 1979 survey of more than 450 Corps of Engineers-operated reservoirs indicated that more than 65 percent have significant problems related to the lack of shoreline vegetation. From spring 1979 through summer 1981 a field study was conducted to identify plant species suitable for revegetating the fluctuation zones of Lake Texoma and similar reservoirs in the south-central United States. Two experimental sites were established at Lake Texoma: a pond where water levels were manipulated (control pool) and a shoreline area subjected to reservoir fluctuations (shoreline site). Ten herbaceous and six woody plant species were transplanted at both sites and evaluated for a variety of survival and development indices to determine suitability for shoreline revegetation applications.

Study Area

2. Lake Texoma was formed in 1944 following completion of Denison Dam. The dam, located on the Red River (Figure 1), is operated for the production of hydroelectric power, for flood control, and for recreation. At the top of the normal pool, the lake covers 89,000 acres* and has a shoreline of 580 miles. The watershed above the dam covers 39,719 square miles.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

3. The study area receives about 34-38 in. of rain per year. Rainfall is erratic, however, and is largely concentrated in spring and early summer. The growing season lasts about 230 days. The vegetation of the Lake Texoma area is primarily oak (*Quercus stellata* and *Q. marilandica*) woodland.* Plant species typical of the true prairie are present, but local soil conditions generally provide soil moisture levels favorable to the growth of trees. A variety of wet-site plants are found along rivers in the area; the most conspicuous are the willows (Salix spp.).

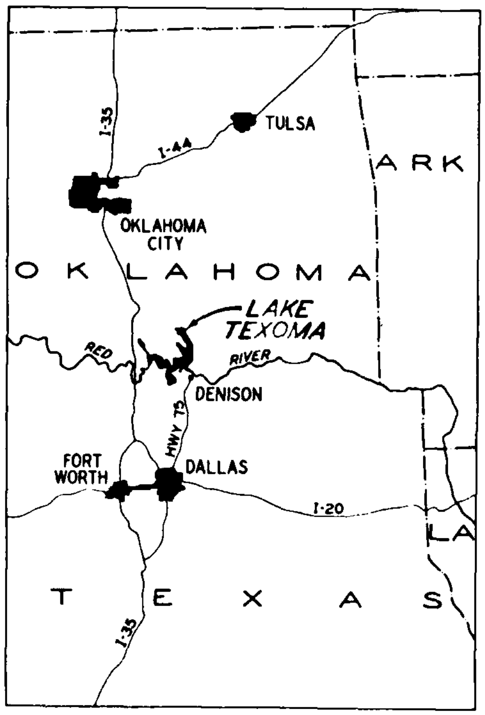

Figure 1. Regional map showing location of Lake Texoma

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* A listing of scientific and common plant names used in this report is provided as Appendix A.

PART II: METHODS AND MATERIALS

Site Preparation

4. The two field sites were established in the spring of 1979. The shoreline site, located near Platter, Okla., was situated on a gently sloping, south-facing shore of Lake Texoma subjected to the normal water level fluctuations of the reservoir. The control pool was an existing, but unused, settling pond near Fink, Tex. It had no hydrologic connection to Lake Texoma, but was outfitted for this study with pump and drainage equipment to permit filling with lake water and controlled drawdown. The control pool had much steeper slopes than the shoreline site.

5. Prior to site development, soils of both areas were sampled and analyzed to determine fertilizer requirements and to check for inhibitory salinity levels. Both sites were characterized by clay-loam soils, although the clay fraction was generally higher in the control pool. Neither site had inhibitory salinity or alkalinity levels; both sites had sufficient levels of essential nutrients, although phosphorus and nitrogen levels were fairly low.

6. Both sites were prepared for planting by disking to depths of about 6 in., rototilling, and raking to obtain a uniform surface. Nitrogen and phosphorus were applied to the sites (at rates calculated to provide optimum levels of both) by broadcasting and raking in pelletized sulfur-coated urea and triple-superphosphate.

7. Species plots were established at both sites by surveying and staking to produce replicated arrays of experimental plantings across a range of elevations. The control pool contained three such replications, each consisting of four elevational tiers. The shoreline site provided more space and a gentler slope; thus, four replications were established, each with five elevational tiers. Dimensions of the species plots varied between sites and years, as discussed in the following paragraphs. Both sites were fenced to exclude domestic livestock.

Transplant Condition

8. Ten herbaceous species were obtained for the 1979 field season. Three additional herbaceous species and six woody species were included beginning with the 1980 field season. All of the transplants were provided by the US Department of Agriculture (USDA) Soil Conservation Service Plant Materials Center in Knox City, Tex. Only one species (*Agropyron smithii*) was in poor condition at the time of planting, which is assumed to have contributed to its subsequent failure. Plant species tested are listed in Table 1, with additional information pertaining to the type and condition of plants at the time of transplanting.

Table 1

Plant Species Tested at Lake Texoma

Species	Year of Planting	Propagule Type	Condition
Herbaceous			
Agropyron smithii	1979	Rhizome	Poor
Arundo donax	1979	Rhizome	Excellent
Buchloe dactyloides	1979	Sod	Excellent
Cyperus esculentus	1979	Bulb	Excellent
Panicum hemitomon	1979	Rhizome	Excellent
Panicum obtusum	1979	Root	Excellent
Panicum virgatum var. "Kanlow"	1979	Root	Excellent
Phragmites australis	1979	Stem cutting	Excellent
Spartina pectinata	1979	Root	Excellent
Tripsacum dactyloides	1979	Root	Excellent
Andropogon glomeratus	1980	Root	Good
Arundinaria gigantea	1980	Root	Good
Paspalum floridanum	1980	Root	Good

(Continued)

Table 1 (Concluded)

Species	Year of Planting	Propagule Type	Condition
Woody			
Amorpha fruticosa	1980	Bare root*	Good
Betula nigra	1980	Bare root	Good
Diospyros virginiana	1980	Bare root	Good
Quercus macrocarpa	1980	Bare root	Good
Salix nigra	1980	Bare root	Good
Sapindus drummondii	1980	Bare root	Good

* Woody transplants were bare root stock averaging 30-60 cm in height.

Experimental Design

9. As indicated in the description of site preparation, both study sites consisted of replicated plantings of small plots across a range of elevations (tiers). Thus, the control pool contained four tiers, each containing one plot for each species, randomized within each tier. This arrangement was replicated three times. The shoreline site was similarly arrayed, but with five tiers and four replicates. The shoreline tiers spanned the following elevations (ft, msl): Tier 1 - 618.9 to 619.0; Tier 2 - 618.5 to 618.6; Tier 3 - 617.9 to 618.1; Tier 4 - 617.3 to 617.4; and Tier 5 - 616.7 to 616.9. Woody and herbaceous species were not mixed within replicates to minimize shading effects.

10. The species plots varied in size between sites (reflecting slope and area available), between years (reflecting problems encountered the first year), and between woody and herbaceous species (reflecting growth form). In 1979, 10 herbaceous species were planted evenly spaced (10 per plot) in 30.5- by 70.0-cm plots at the control pool and in 30.5- by 140-cm plots at the shoreline site. Three additional herbaceous species planted in 1980 were also arranged 10 per plot, but plot dimensions were 45.7 by 70.0 cm at the control pool and

45.7 by 140.0 cm at the shoreline site. The six woody species planted in 1980 were planted nine per plot in 140.0- by 140.0-cm plots at the control pool and eight per plot in 70.0- by 167.6-cm plots at the shoreline site. In all cases, plots were separated by walkways sufficient to prevent crowding from adjacent plots and to ensure distinctly different inundation characteristics from adjacent tiers. Throughout the study, the sites were maintained to minimize confounding effects such as transplant desiccation and weed invasion. Plots were weeded regularly, especially during initial plant establishment, and irrigation water was applied to newly transplanted plots. Incidents of vandalism and breaches of the fence by cattle occurred, but were either repaired satisfactorily or taken into account during subsequent data analyses.

11. The treatment applied to the transplants was inundation, as outlined in Table 2. It should be recognized that this simple expression of treatment (as number of days the soil was flooded) reflects a complex of factors, all of which may influence plant success. Not quantifiable are such related factors as depth of flooding, ground-water levels, drought effects, and soil temperatures. Further, the timing of flooding (initiation and drawdown dates, see Table 2) may also influence the performance of transplants. As Table 2 indicates, this experiment subjected plants to a variety of flooding conditions representing a broad range of potential realistic field applications. As planned, the uppermost plots (tier 1) at the control pool remained unflooded throughout the study, while the lowest shoreline plots (tier 5) were inundated throughout nearly all of the first growing season. Generally, the duration of flooding of each tier remained constant from year to year at the control pool, but flooding in 1980 was initiated a month earlier than the previous year, and another month earlier in 1981. In contrast, flood initiation dates remained relatively constant on the shoreline, but flood durations varied considerably between years and tiers. This variation in treatments greatly reduces comparability between sites, but at the same time it represents a realistic range of potential inundation conditions that provide insight on the ability of the tested species to persist in a lakeshore environment. Thus, while rigorous statistical

Table 2

Inundation Schedule

	Control Pool					
	1979		1980		1981	
Tier	Period of Inundation*	No. of Days	Period of Inundation*	No. of Days	Period of Inundation*	No. of Days
1	No inundation					
2	13-30 Jul	17	20 Jun-7 Jul	17	15 May-5 Jun	21
3	13 Jul-13 Aug	31	20 Jun-22 Jul	32	15 May-19 Jun	35
4	13 Jul-27 Aug	45	20 Jun-6 Aug	47	15 May-3 Jul	49
5	N/A		N/A		N/A	

	Shoreline Site					
	1979		1980		1981	
Tier	Period of Inundation*	No. of Days	Period of Inundation*	No. of Days	Period of Inundation*	No. of Days
1	10-18 Jun	8	2- 6 Jun	4	3-19 Jun	16
2	9-22 Jun	13	2-11 Jun	9	1-21 Jun	20
3	23 May-27 Jun	35	1-15 Jun	14	30 May-26 Jun	27
4	22 May-4 Aug	74	1 Jun-4 Jul	34	27 May-9 Jul	42
5	13 Apr-5 Sep	145	31 May-12 Jul	43	10 May-18 Jul	69

* Represents date of initiation of flooding through drawdown date.

analysis of treatment effects is precluded here, simple graphical displays of performance can be interpreted in the context of a complex of varying treatment conditions to derive an overall assessment of the limits and potential of each tested species.

Soil and Water Measurements

12. As noted earlier, basic soil characteristics were evaluated prior to planting to determine fertilizer requirements and assess variability between and within sites. In addition, soil samples were periodically taken throughout the study to monitor changes in selected characteristics. Samples were taken from each tier in each replicate 2 weeks after exposure of the tier in 1979 and 1980. A single preinundation sample was collected from all tiers and replicates in 1981. All samples were analyzed for salinity, electrical conductivity, cation exchange capacity, exchangeable bases, pH, total nitrogen, and exchangeable phosphorus. Field measurements of redox potential were taken. Annual measurements were made of erosion and sedimentation using marked reference stakes in each tier and replicate.

13. Water quality samples were taken three times during each growing season to monitor for potential adverse conditions associated with impounded waters and the relatively high salinity of the Red River. At each sampling occasion triplicate samples were taken from the upper edge of standing waters within the experimental site. Measurements taken included temperature, turbidity, electrical conductivity, redox potential, and biological oxygen demand.

Transplant Performance Monitoring

14. All exposed plots were evaluated for a range of plant performance indicators three times each year. In the control pool, sampling was conducted approximately 1 week after each water level drawdown. Sampling of the shoreline site plots was more irregular due to the unpredictability of lake fluctuations, but was scheduled to allow

evaluation within a few weeks of exposure of each tier. In addition, special sampling efforts were scheduled as necessary to document recovery from initial transplanting shock and damage due to grazing and vandalism incidents. One poststudy reassessment of the shoreline site was made in October 1982 to provide an indication of the performance of established plants in an unmanaged site following a summer of extreme inundation. Plant performance was assessed at each sampling occasion using the methods described below.

Herbaceous species

15. Survival. Due to the tendency of most of the herbaceous species to reproduce vegetatively, survival of individual transplants could not be reliably determined. Instead, each plot was rated for survival based on the presence or absence of the transplanted species anywhere within the plot boundary.

16. Cover. Foliage cover of each plot was visually estimated as a percentage of total plot area using a seven-class cover scale. Midpoints of each cover class were used for subsequent analyses.

17. Stem density. In 1979 and 1980, total stem counts were made for each species (except *Buchloe dactyloides* and *Tripsacum dactyloides*, whose growth habits precluded density evaluation).

18. Height. Maximum height was recorded for 8 to 10 randomly selected individuals in each plot. In plots with less than 10 surviving stems, all plants were measured.

19. Phenology. One or more phenological (reproductive) codes were assigned to each plot, reflecting the ability of the transplants to complete their life cycles.

20. Vigor. A six-class vigor code was used to assess the overall health and condition of the plants in each plot.

Woody species

21. Survival. Survival of each individual transplant was readily determined for the woody species; thus, total transplant counts were conducted in each plot.

22. Height. All surviving individuals were measured, and average height of survivors was calculated for each plot.

23. Cover. Two canopy diameter measurements were taken perpendicular to one another on a horizontal plane through the broadest part of each woody plant canopy. The average diameter value was used to calculate area of a circle, which was taken to be a reasonable estimate of total canopy cover for each plant. Coverages were summed for each plot. Note that overlapping canopies may result in total plot coverage values that exceed the actual area of the plot.

24. Phenology. (This parameter was determined as for herbaceous species.)

25. Vigor. (This parameter was determined as for herbaceous species.)

PART III: RESULTS

Site Conditions

26. The inundation schedules at the two study sites, described in Part II and summarized in Table 2, show that the treatment of primary interest (growing season flooding) was applied to the experimental plots in a manner that provided a broad range of inundation durations and depths that occurred at various times during the growing season. While flooding was presumed to be the environmental variable having the greatest influence on transplant performance, it must be recognized that successful species must also tolerate periods of drought and cold winter temperatures. The USDA weather station at Durant, Okla., recorded slightly colder than normal temperatures during all three study years, with average departures of -3.8 to -1.5° F. Rainfall was less than normal (40.22 in.) in 1979 (-1.0 in. departure) and 1980 (-7.11 in. departure), but was well above normal in 1981 (+9.26 in. departure). July and August, when most plots were not inundated, were hot and dry during each year of study.

27. Soil chemical properties showed little variation that was related to study sites or to the transplant species occupying the sample site. However, electrical conductivities rose somewhat immediately following disturbance of the substrate in 1979, and there was some tendency for certain values (conductivity, chlorides, sodium, magnesium, calcium) to be higher in the most-flooded (lowest) tiers than in the highest tiers. Overall, however, changes in soil properties tended to be minor, and conditions potentially limiting to plant growth did not occur. Erosion and sedimentation data showed similar minor variations, with a net accumulation of material on both sites in 1979 and 1981, and a net loss in 1980. In most cases, losses and gains were less than 2 cm in magnitude, and no adverse effects on transplants were apparent.

28. Water quality data from both sites also showed no evidence of conditions likely to seriously impact transplant performance. Generally, biological oxygen demand, turbidity, conductivity, and redox

potential were highest in 1979, apparently reflecting site disturbance and fertilization. Conductivity remained high through the low-rainfall year, 1980. In 1981, site stability and increased rainfall contributed to lowered values for all water quality parameters except biological oxygen demand, which rose in response to the warm, wet growing season conditions.

Transplant Performance

Herbaceous species

29. Thirteen herbaceous species were evaluated during the course of the study. Of these, *Agropyron smithii*, *Andropogon glomeratus*, and *Arundinaria gigantea* suffered nearly complete mortality shortly after being transplanted to the sites. Since no conclusions can be drawn regarding the cause of this mortality (inundation versus failure of transplants to establish), these three species will be eliminated from further analysis and discussion.

30. Transplant survival is not used as the principal criterion of success in the individual species results presented below. The inability to distinguish individual transplants and the resultant reliance on simple presence/absence ratings for each plot greatly limit the usefulness of survival as an indicator of herbaceous plant success. Further, it was impossible (due to a rapid rise in lake levels) to fully evaluate transplant mortality following initial planting, and thereby to correct the final survival data to reflect only treatment effects. Given these limitations, survival data will not be referenced in the species discussions. However, total survival at the end of the study (July-August 1981) is presented in Table 3 to provide a general indication of the overall establishment and persistence of each species. These data indicate that survival was fairly uniform between sites and replicates within each species.

31. Stem density also proved to be of limited usefulness as an indicator of the success of herbaceous species. Generally, stem densities varied more as a function of species growth habit and seasonal

changes in productivity than as a direct reflection of response to inundation treatments. These limitations, coupled with methodological problems in obtaining stem counts, prompted elimination of this criterion from the field effort after two seasons, and it will not be considered further.

Table 3

Transplant Survival* at Experimental Sites

July-August 1981

Species	Tier, Control Pool 1	2	3	4	Tier, Shoreline Site 1	2	3	4	5
Arundo donax	100	100	100	100	100	100	100	100	25
Buchloe dactyloides	100	66	66	66	100	100	100	0	0
Cyperus esculentus	100	33	66	66	100	100	50	0	0
Panicum hemitomon	33	100	0	0	100	75	25	50	0
Panicum obtusum	100	100	100	33	100	100	100	0	0
Panicum virgatum	100	100	100	66	100	100	100	50	0
Phragmites australis	66	66	66	100	100	100	100	100	50
Spartina pectinata	100	100	100	66	100	25	50	25	25
Tripsacum dactyloides	100	100	0	0	100	100	75	0	0
Paspalum floridanum	66	66	0	0	100	100	75	50	50
	(0)**	(21)	(35)	(49)	(16)	(20)	(35)	(74)	(145)

* Expressed as percentage of initially planted plots still supporting one or more living individuals of the species tested.

** Numbers in parentheses indicate the maximum number of days flooded per tier in any of the 3 years of the study.

32. The best overall descriptor of herbaceous species success in this study is cover, which integrates survival and productivity to provide an indication of a species' ability to occupy an environment into which it has been introduced. Cover data presented here are the percent cover values for all occupied plots within a tier and site for each species. Only end-of-season data for each year are presented to avoid

complicating the primary issues of interest with seasonal developmental trends.

33. Plant height has also been selected as an informative variable. While providing some indication of treatment effects, end-of-season height data are probably most useful as they illustrate the inundation depth limitations of each species. Similarly, phenology and vigor information are useful to refine understanding of the apparent inundation tolerance of each species and to identify the range of conditions under which a species can be expected to perform well.

34. The performance of each herbaceous species is reviewed in the following paragraphs.

35. *Arundo donax* was among the most successful herbaceous species tested. As Figure 2 illustrates, it persisted across all tiers and years at the control pool, reaching and sustaining 100-percent cover in all tiers by the second year after planting. On the shoreline site it

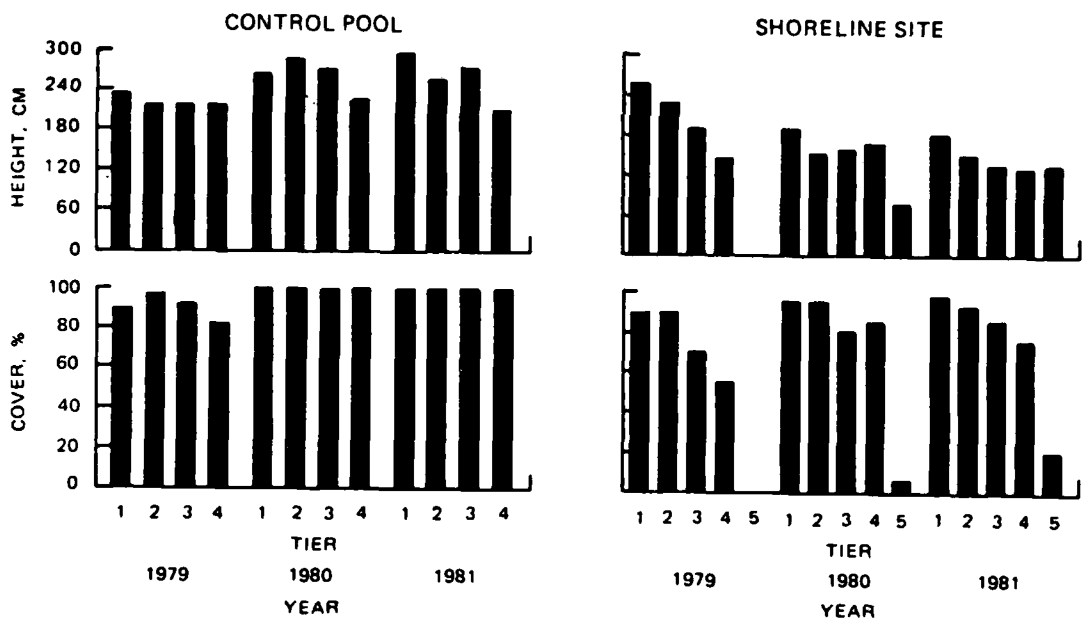

Figure 2. *Arundo donax* cover and height

recovered from apparent elimination from the lowest tier in 1979, and plants in all tiers produced fruits in 1981. However, depressed heights and coverage in the lowest shoreline tiers suggest that this species approached its tolerance limits on those sites.

36. *Buchloe dactyloides* (Figure 3) exhibited a distinct inundation tolerance threshold on the shoreline site, where it did not survive after 74 days of flooding in 1979. It persisted in all tiers at the control pool, but was much less successful in the 6-week flood zone (tier 4) than in higher tiers. This sod-forming grass showed consistent vegetative spread in all tiers in which it survived, and some flowering occurred in 1979.

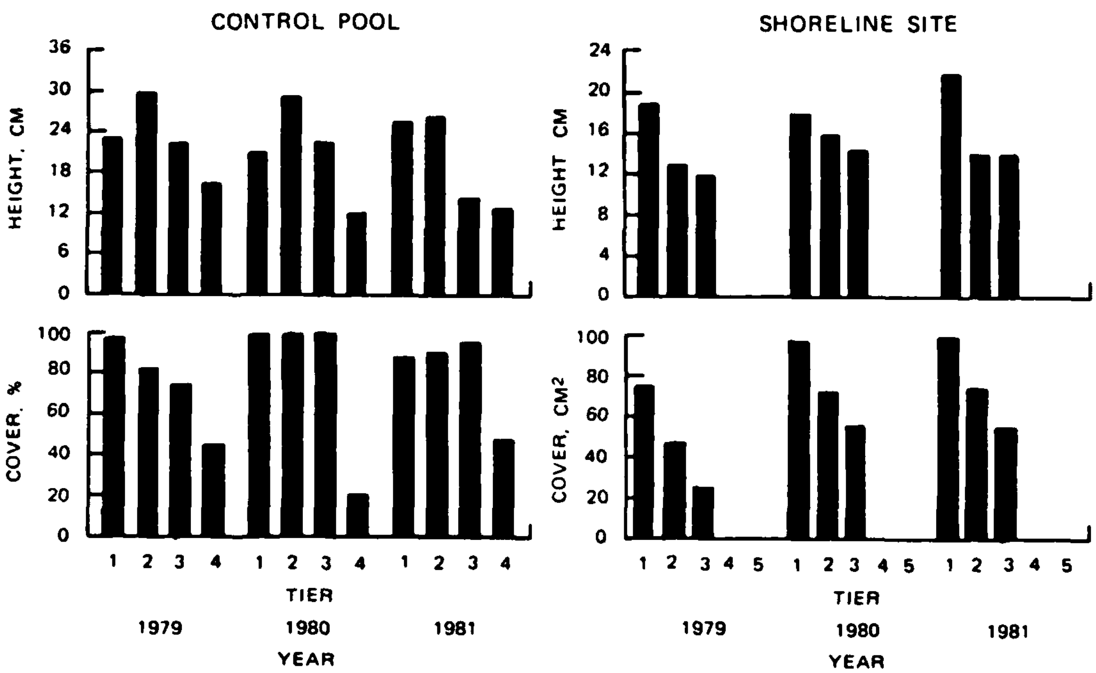

Figure 3. *Buchloe dactyloides* cover and height

37. *Cyperus esculentus* persisted across all tiers at the control pool and across three tiers at the shoreline site, but was eliminated where flooding of more than 7 weeks duration occurred (on average) (Figure 4). Despite this apparently high level of inundation tolerance, this species cannot be regarded as performing successfully on any tier

or site. As Figure 4 illustrates, *C. esculentus* never surpassed 40-percent cover at any time during the study. Flowering and vegetative spread were rarely noted, and new growth was consistently evident only in the control pool.

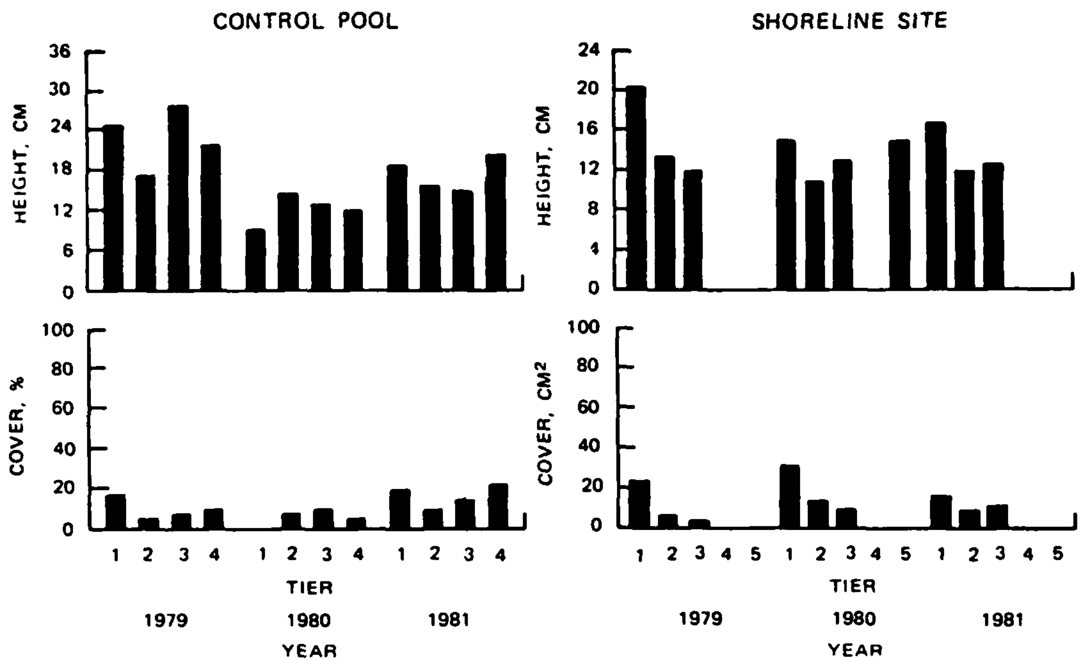

Figure 4. *Cyperus esculentus* cover and height

38. *Panicum hemitomon* (Figure 5) displayed a distinct affinity for sites flooded 1-3 weeks each year (tier 2 at the control pool and tier 1 on the shoreline). Coverage on these sites varied from 40 to 60 percent in 1980 and 1981, but plants on wetter and drier sites never surpassed 20-percent coverage in any year. Height growth was erratic, but plants tended to be tallest in the same tiers where best coverage was achieved. Overall, new growth was observed less frequently as the study progressed, and no flowering or fruiting was ever noted.

39. *Panicum obtusum* survived in all tiers at the control pool but was eliminated from shoreline site tiers 4 and 5, where average annual flooding exceeded 7 weeks (Figure 6). Best coverage (nearly 80 percent)

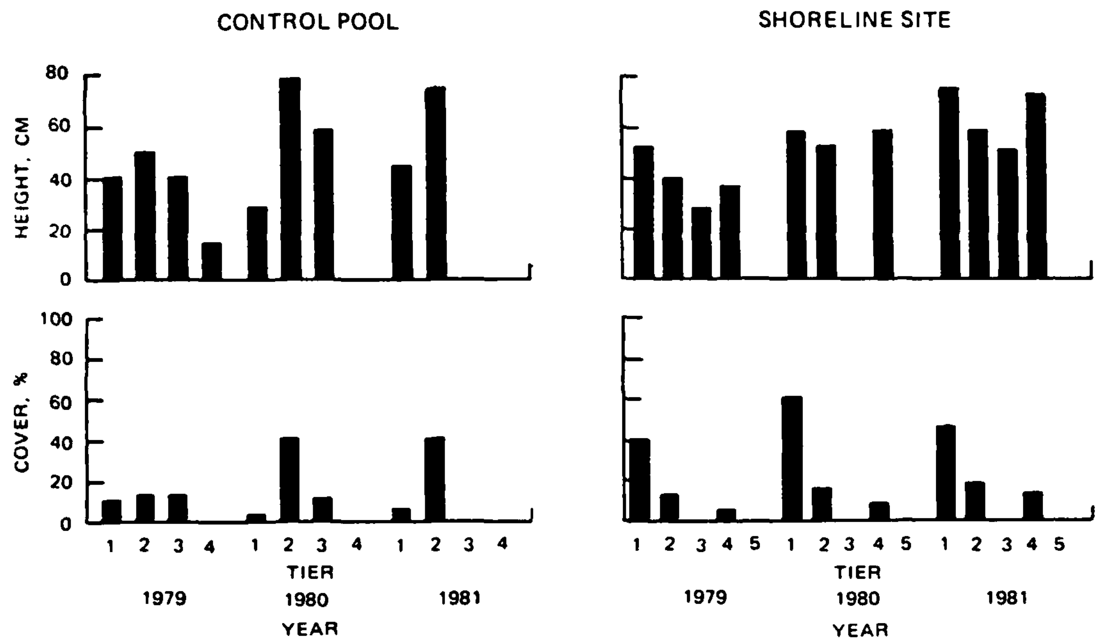

Figure 5. *Panicum hemitomon* cover and height

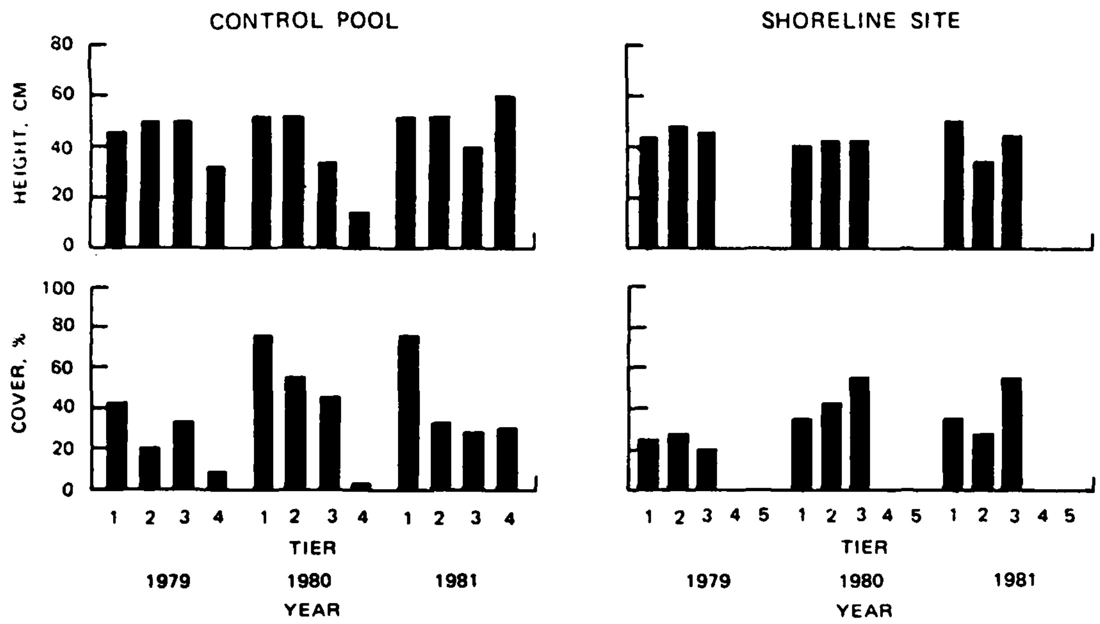

Figure 6. *Panicum obtusum* cover and height

was achieved in the unflooded tier at the control pool. Within flooded zones, the only tiers where coverage exceeded 50 percent at any time were those subjected to an average of 2-3 weeks of inundation each year. Despite relatively poor performance in the lower tiers, all sites where plants persisted continued to show new growth or vegetative spread in all years, and plants of the upper three tiers of the shoreline site produced fruits in 1980 and 1981.

40. *Panicum virgatum* var "Kanlow" (Figure 7) was among the most successful of the species evaluated in this study. It survived and attained good coverage at both sites in all but the lowest shoreline tier, where it was eliminated by 145 days of inundation in 1979. This species consistently improved its coverage as the study progressed, achieving better than 80-percent cover in all control pool tiers and better than 50-percent cover in four shoreline site tiers by the end of the 1981 season. Flowering and fruit production occurred commonly in all years of study.

41. *Phragmites australis* survived in all tiers at both sites throughout the study (Figure 8). However, coverage never exceeded 40 percent in any tier and had declined to less than 20 percent in all tiers at both sites by the end of the 1981 season. Heights tended to increase slightly or remained stable as the study progressed, and some fruit production was noted at the shoreline site in 1980.

42. *Spartina pectinata* (Figure 9) showed good response to treatment at both experimental sites. This species survived in all tiers, and coverage increased consistently over the years of study. By the end of 1981, coverage exceeded 80 percent in all tiers at the control pool. Tiers 3 and 4 (3 to 7 weeks of inundation on average) had the best coverage at the shoreline site (70 to 80 percent). Flowering and fruiting were noted throughout all tiers and years at the shoreline. Control pool plants flowered in 1979 and 1980.

43. *Tripsacum dactyloides* was sharply restricted to sites where flooding averaged less than 4 weeks duration (Figure 10). It performed very well (coverages of 90 to 100 percent) in all tiers flooded for 2 to 3 weeks or less, and coverage was good (60 percent) in tier 3

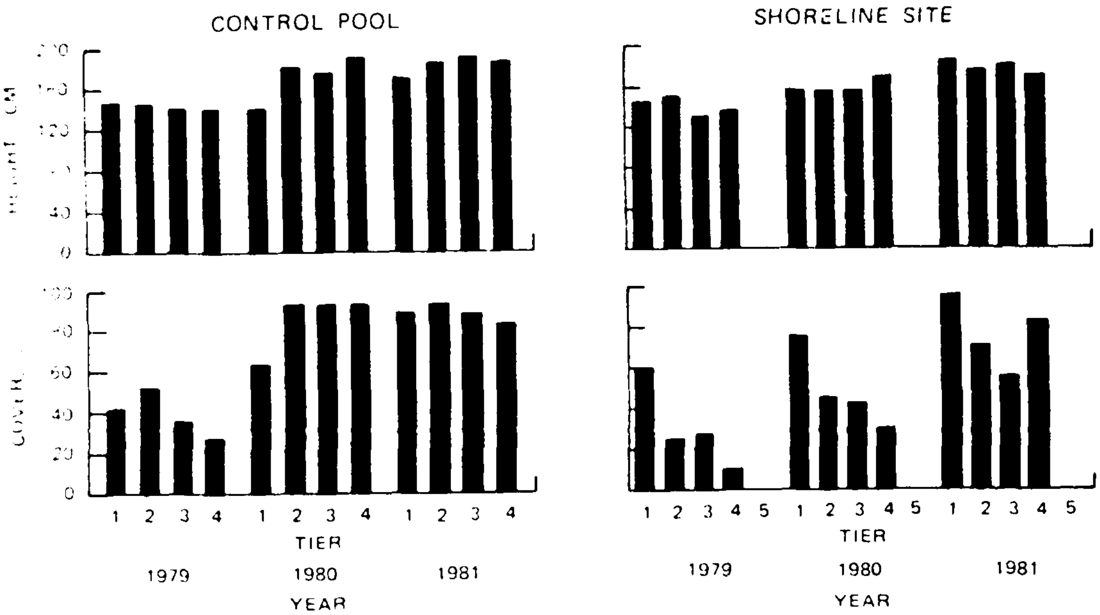

Figure 7. *Panicum virgatum* cover and height

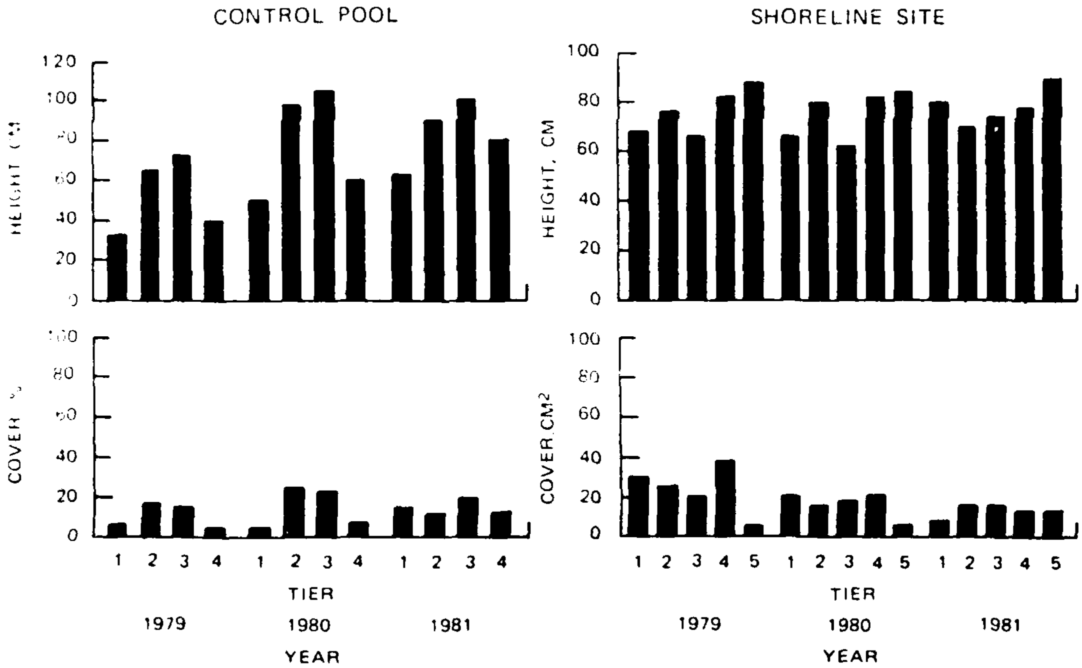

Figure 8. *Phragmites australis* cover and height (Note that height scales differ between sites.)

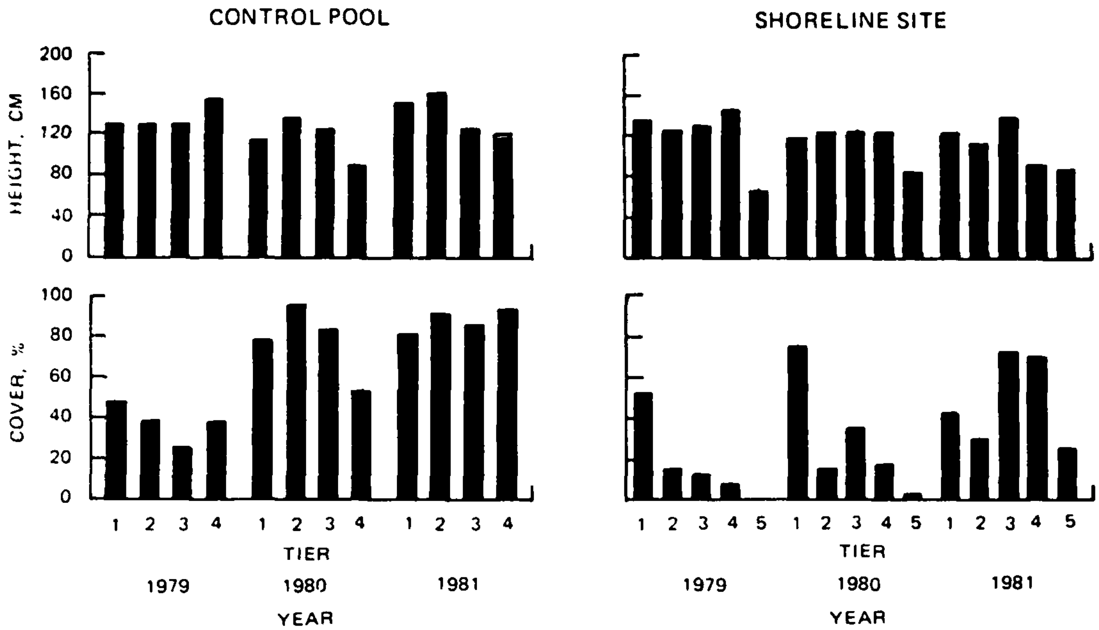

Figure 9. *Spartina pectinata* cover and height

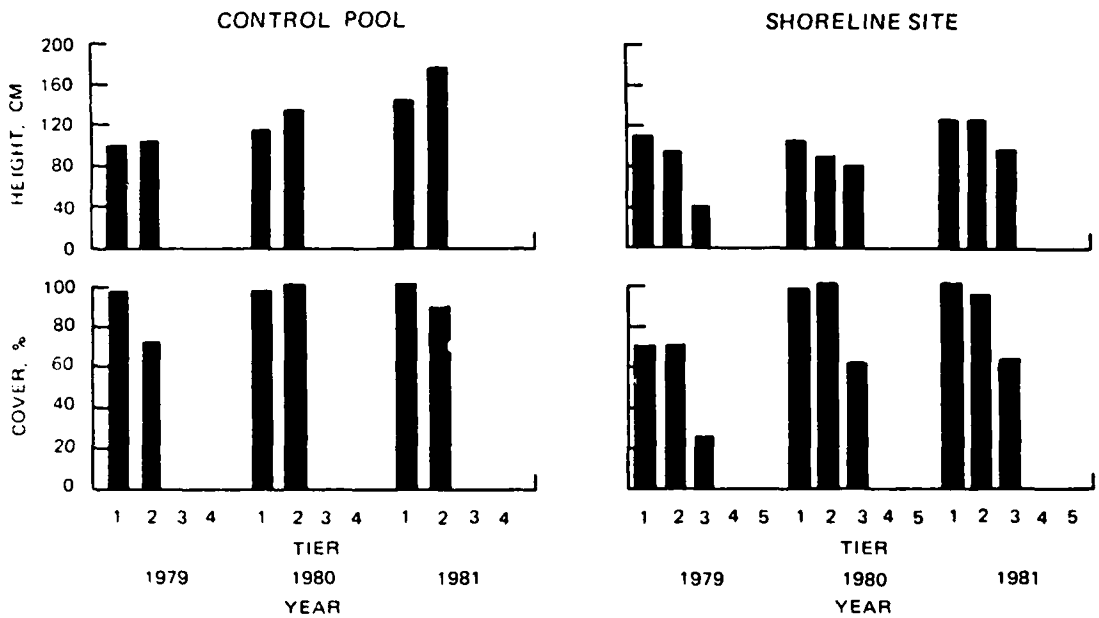

Figure 10. *Tripsacum dactyloides* cover and height

(3.6 weeks average inundation) on the shoreline. Vegetative spread and limited fruit production were evident on all sites. Height growth was consistently greater in the control pool.

44. *Paspalum floridanum* was not planted until 1980 and did not achieve coverages of more than 30 percent on any sites or tier in that year (Figure 11). By the end of 1981, it had been eliminated from all tiers where inundation exceeded 5 weeks in duration. In those tiers where this species survived, cover had improved consistently by the end of 1981, although best coverage was achieved in the unflooded tier in the control pool. On the shoreline, the only tier where cover exceeded 50 percent was tier 2 (3 weeks of flooding). Some flowering occurred in all occupied tiers at both sites over the 2 years of study.

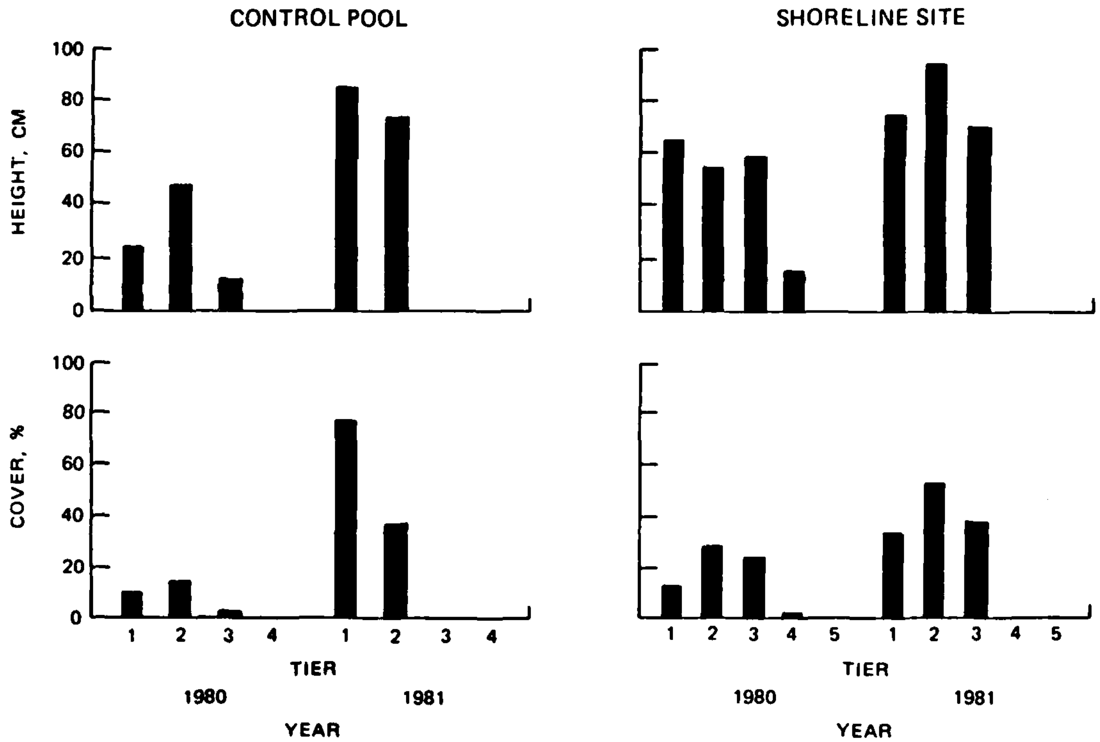

Figure 11. *Paspalum floridanum* height and cover

Woody species

45. In contrast to the herbaceous species, the woody transplants lent themselves well to evaluation of survival. Since the position of each original transplant was readily identifiable, total stem counts were obtained at each monitoring period. The graphic presentations of these data reflect the percentage of original transplants still surviving at the end of each growing season. They are not corrected for initial, pretreatment mortality to allow comparison with plot cover data. However, pretreatment mortality was surveyed in 1980 and is noted in the individual species discussions.

46. Height and cover are also used here as key indicators of plant response to inundation. Both are calculated from end-of-season data. Heights of surviving individuals were averaged across tiers for each species and site, and are indicative of overall growth. Similarly, cover values were summed for each plot and averaged across tiers for each species.

47. None of the woody transplants matured sufficiently to produce flowers, as expected. Vigor is closely reflected by height growth, and is not specifically discussed in the individual species assessments presented below.

48. *Amorpha fruticosa* (Figure 12) performed very well at both study sites over 2 years of treatment and monitoring. Overall initial transplant mortality (1980 preinundation) was the lowest of all woody species (3.4 percent on the shoreline and 8.4 percent at the control pool). Survival remained greater than 60 percent in tiers flooded less than 4 weeks at both sites. A few individuals tolerated nearly 10 weeks of inundation on the shoreline in 1981, but all were eliminated after 7 weeks of flooding (tier 4) at the control pool in 1980. Similar survival patterns were seen in several other woody species, which suggests that a complex of factors (deeper flooding, steeper slope, slightly droughtier soils) contributed to higher mortality among the woody transplants at the control pool in the extremely dry summer of 1980. Stressful conditions in 1980 may also explain a phenomenon seen in the survival data for most of the woody species, including *A. fruticosa*: the

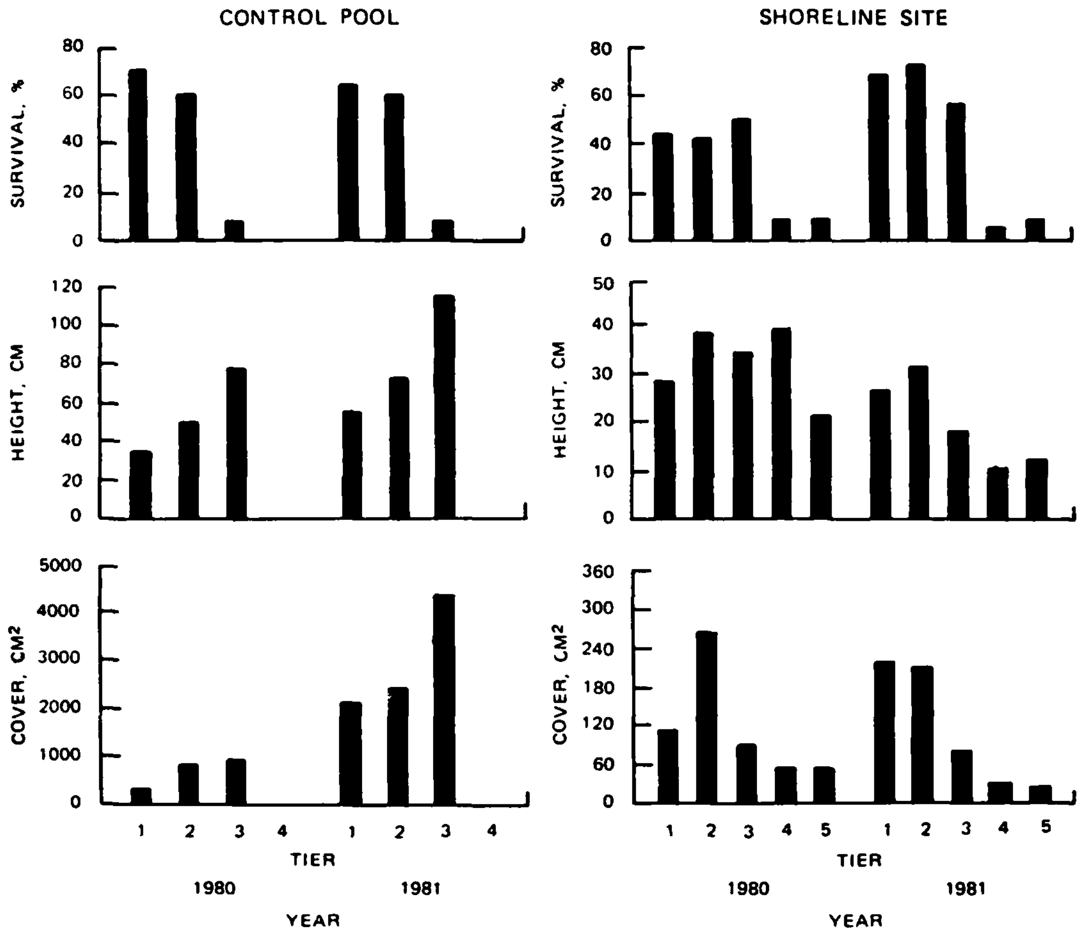

Figure 12. *Amorpha fruticosa* survival, height, and cover (Note that scales vary between sites.)

apparent increase in survival recorded in 1981 is obviously the result of misclassifying extremely stressed individuals as dead at the end of the 1980 field season. Despite their poor condition in late summer of 1980, many of these individuals were able to recover sufficiently to resume growth and tolerate inundation treatments in 1981. The apparent reduction in height of some species between 1980 and 1981 may represent a similar response to environmental stresses in 1980, or it may reflect overwinter shoot damage.

49. Examination of height and cover data for *A. fruticosa* indicates that this species continued to grow well at the control site in

1981. Cover increased nearly 400 percent in tier 3, which was flooded for 35 days in 1981. In contrast, height and cover values consistently declined on the shoreline site in 1981, despite overall better survival.

50. *Betula nigra* suffered initial transplant mortality of about 60 percent at both sites prior to any inundation treatment. Among survivors, losses were high by the end of 1981 (Figure 13), although a pretreatment survey in May 1981 indicated that most of these losses occurred over winter. This species was completely eliminated at the control pool, and suffered nearly 50-percent mortality on the shoreline

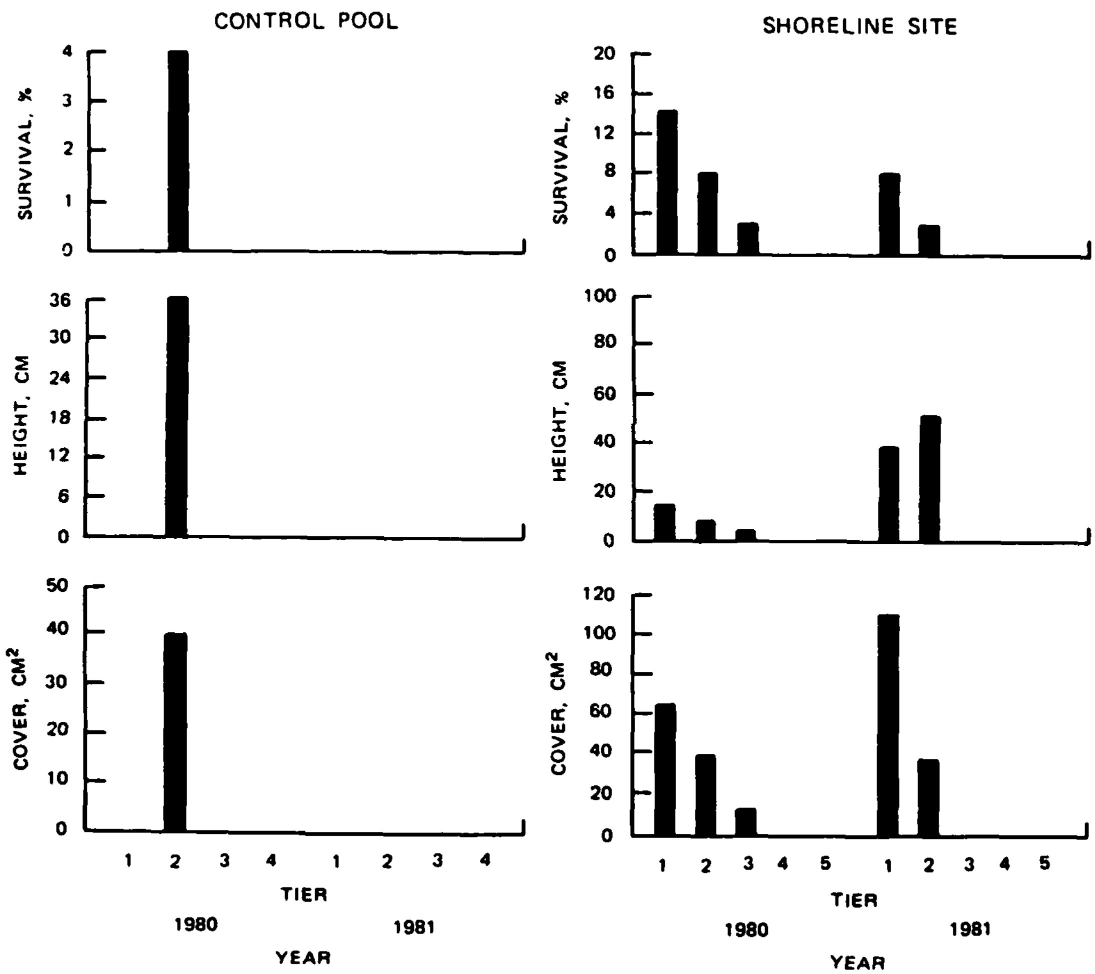

Figure 13. *Betula nigra* survival, height, and cover (Note that scales vary between sites.)

site. The few individuals remaining at the end of 1981 showed good gains in coverage and height growth only in the uppermost tier, inundated just 16 days in 1981.

51. *Diospyros virginiana* (Figure 14) had apparent pretreatment mortalities exceeding 60 percent on both sites. Nearly all of the surviving transplants successfully tolerated up to 3 weeks of inundation on both sites, and some individuals persisted through 5 weeks of flooding at the control pool and 10 weeks at the shoreline. Many of these

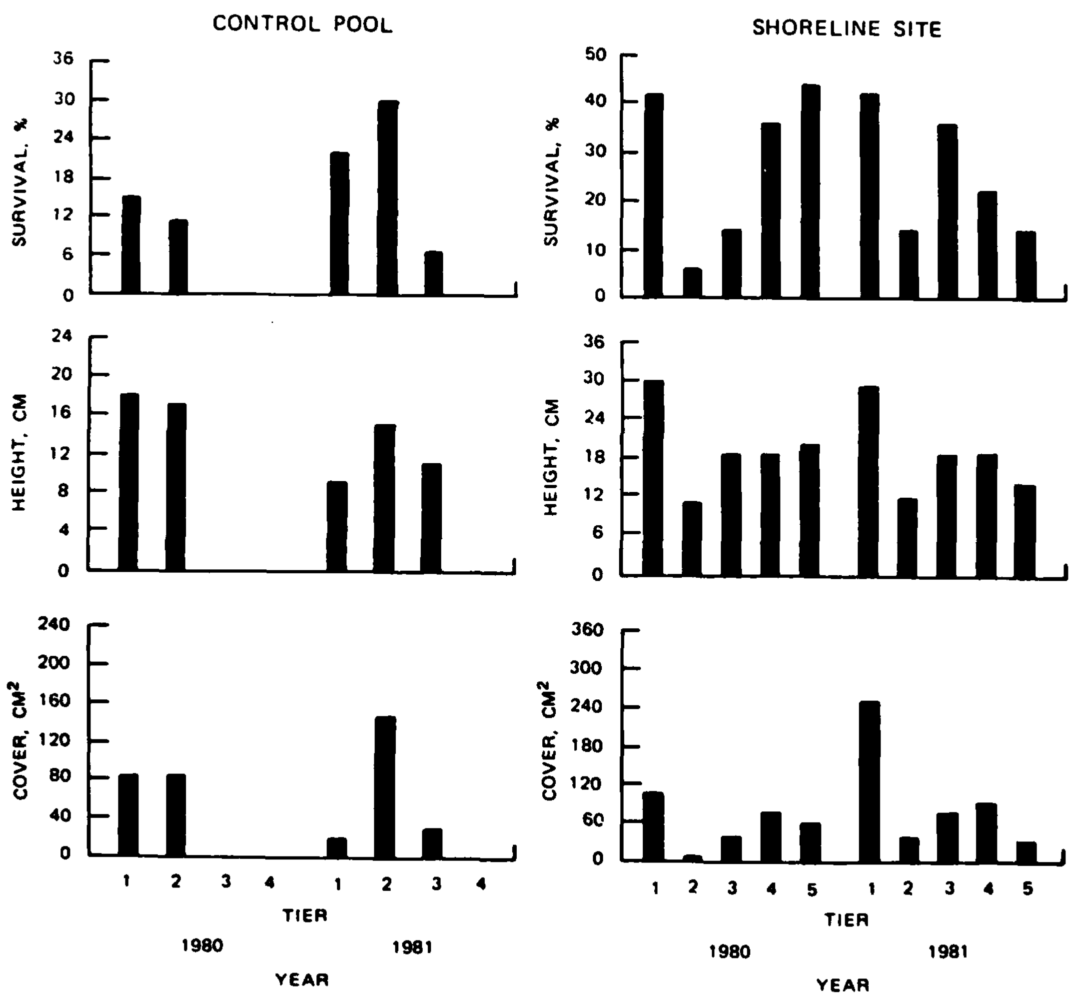

Figure 14. *Diospyros virginiana* survival, height, and cover (Note that scales vary between sites.)

survivors were clearly very stressed, however, as evidenced by their misclassification as "dead" at the end of the 1980 season and the lack of increases in height growth from 1980 to 1981. Some increases in coverage were recorded between years, but these were notable only in the 2- to 3-week inundation zones on both sites. Nevertheless, this species has potential for revegetation of shorelines because of its tolerance to 10 weeks of flooding and its drought tolerance.

52. *Quercus macrocarpa* suffered highly variable preinundation mortalities between sites and between tiers at the control pool. Average initial mortality at the shoreline site was about 22 percent (range: 11 to 30 percent); at the control pool, the upper two tiers had preinundation mortalities averaging 27 percent, while the lower two tiers suffered an average 50-percent loss. Examination of Figure 15 in light of these initial survival figures indicates that inundation and/or drought in 1980 eliminated individuals on the lowest tier at both sites, sharply reduced survival in the upper two tiers at the shoreline, and killed half of the survivors in tier 2 at the control pool. However, individuals that survived at the end of 1980 were nearly all still present after treatment in 1981, except for those that received 6 weeks of flooding on the shoreline. No notable height gains were recorded on any tier or site, but coverage improved substantially at both sites in tiers that were flooded for 3 weeks in 1981.

53. *Sapindus drummondii* suffered the most severe preinundation mortality of all the woody species: 82 percent at the control pool and 72 percent at the shoreline. By the end of the 1980 season, this species had been completely eliminated from tiers 3 and 4 at the control pool and tier 3 on the shoreline (Figure 16). Despite good growth in tiers 4 and 5 in 1980, trees in these tiers suffered complete mortality in 1981. Height and coverage of survivors declined on the shoreline in 1981, as did survival in tier 1 of the control pool. Only plants of tier 2 at the control pool (3 weeks of inundation) suffered no mortality and increased in height and coverage during the 1981 season.

54. *Salix nigra* had preinundation mortalities of 27 percent at the control pool and 13 percent on the shoreline. By the end of 1980,

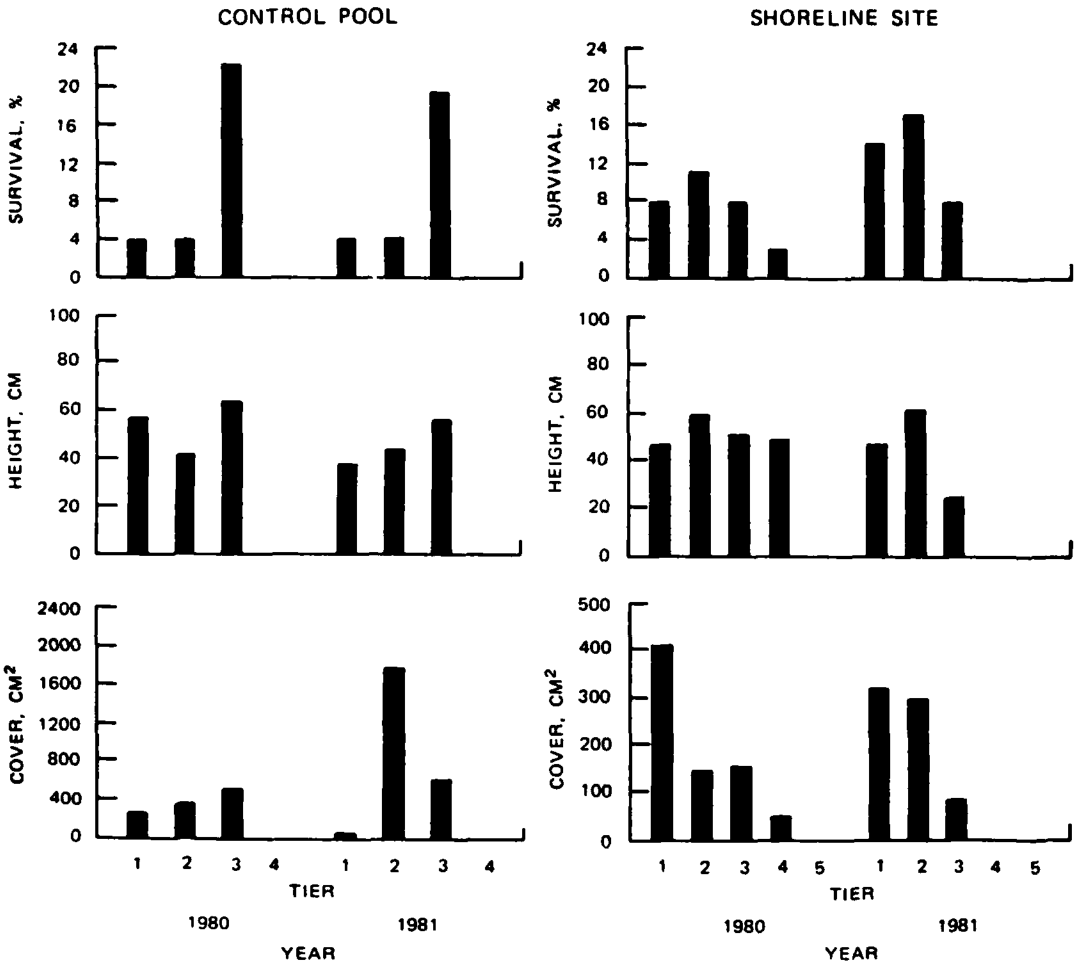

Figure 15. *Quercus macrocarpa* survival, height, and cover (Note that scales vary between sites.)

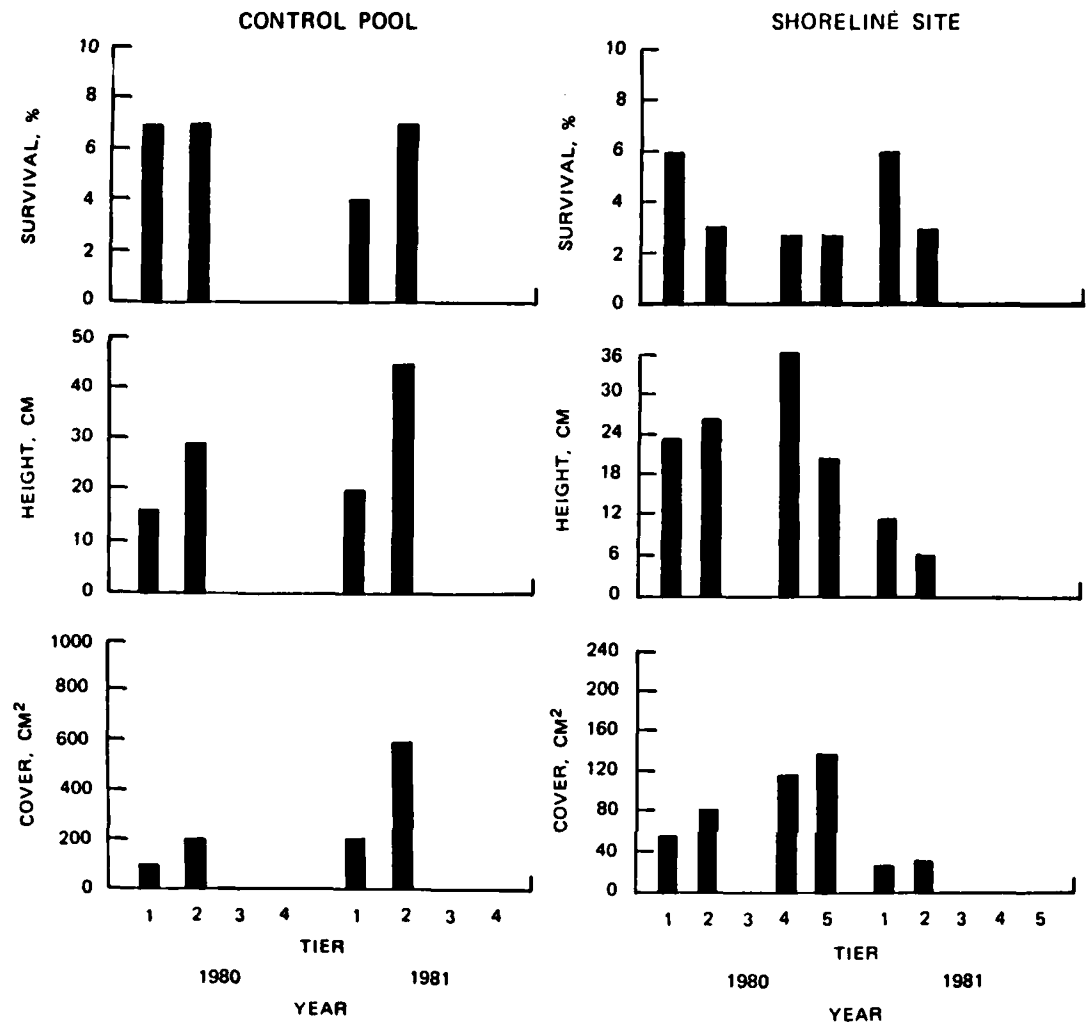

Figure 16. *Sapindus drummondii* survival, height, and cover (Note that scales vary between sites.)

no tier on either site had better than 50-percent survival, and the lowest control pool tier had no survivors remaining (Figure 17). At the end of the 1981 field season, only tiers 2 and 3 at the control pool (3-5 weeks of flooding) still supported transplants, and these had increased in height and coverage since 1980. In contrast, the shoreline site retained survivors on all tiers during both years of the study. Performance on this site was erratic, with best survival in the zones

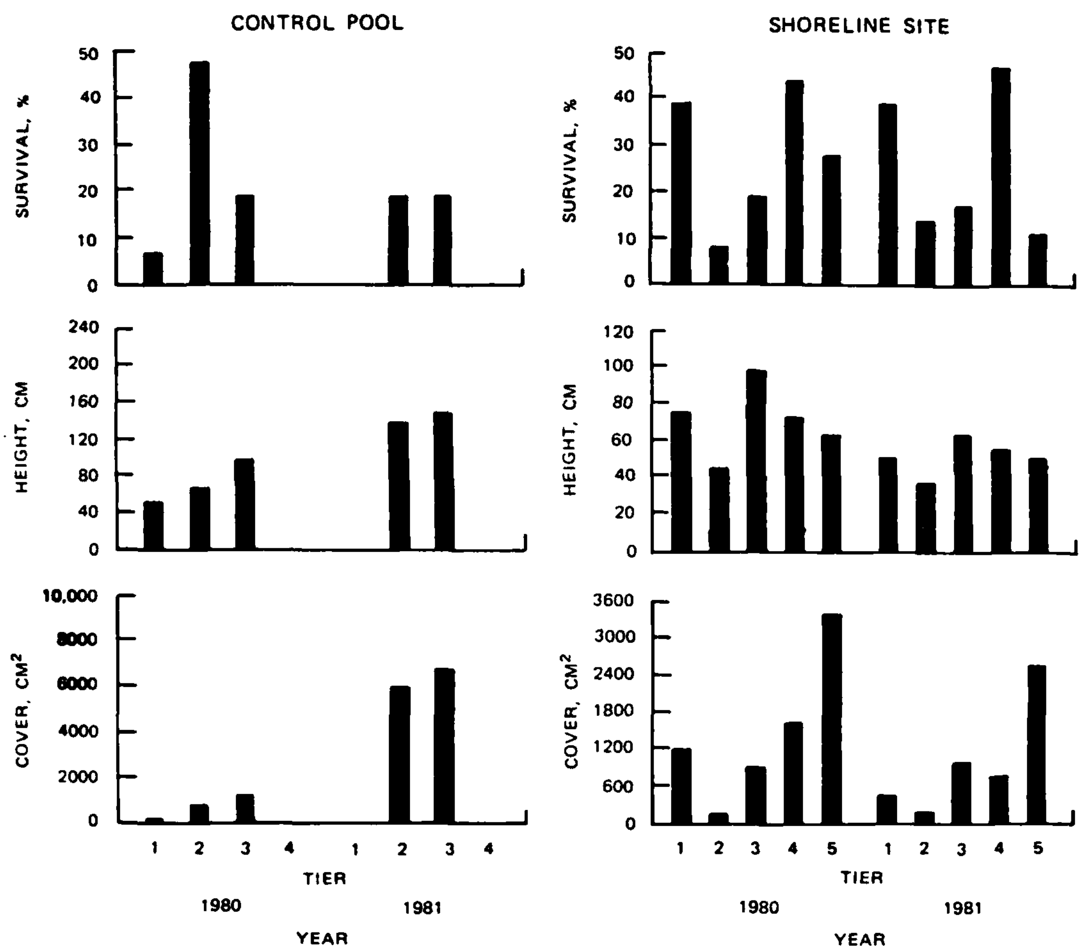

Figure 17. *Salix nigra* survival, height, and cover. (Note that scales vary between sites.)

flooded for 2 weeks (tier 1) and 6 weeks (tier 4) in 1981, while best coverage was attained in the zone that retained only a few surviving plants (tier 5, flooded 10 weeks in 1981).

October 1982 Reconnaissance

55. Although this experiment was formally terminated at the end of the 1981 growing season, one additional survey was conducted at the shoreline site in October 1982. Since inundation had been extreme during the summer, the survey was conducted to evaluate the ability of established plants to endure prolonged flooding without special attention to site maintenance (weeding, debris removal, etc.).

56. Lake Texoma rose rapidly in mid-May 1982 (Table 4), soon after plants on the shoreline site had broken dormancy.

Table 4

Inundation of the Shoreline Site, Lake Texoma, 1982

Tier	Days Flooded	Period of Inundation
1	63	15 May-16 Jul
2	67	14 May-19 Jul
3	72	14 May-23 Jul
4	91	13 May-11 Aug
5	99	12 May-18 Aug

57. At the time of the reconnaissance, four herbaceous species (*Arundo donax*, *Buchloe dactyloides*, *Tripsacum dactyloides*, and *Paspalum floridanum*) appeared to have suffered complete mortality in all plots. Root systems of the latter three species were exposed and desiccated, indicating that they had, indeed, been eliminated by the prolonged flooding. The fate of *Arundo donax* was less certain; given the massive root system of this species and its previously demonstrated ability to

recover from apparent elimination (Figure 2), *Arundo* may not have been completely killed in all tiers. Among species that were clearly alive in October 1982, none was robust, and no species had more than 16-percent cover in any tier. Nevertheless, three species (*Cyperus esculentus, Panicum virgatum*, and *Phragmites australis*) maintained some survival in all tiers that still had survivors at the end of the 1981 growing season. *Panicum hemitomon* and *Panicum obtusum* were still present in the upper two tiers, and *Spartina pectinata* remained in all plots in the top tier.

58. The woody species were similarly impacted by the 1982 extended inundation. *Betula nigra* and *Sapindus drummondii* were completely eliminated from all plots, *Quercus macrocarpa* was present only in the top tier, and *Amorpha fruticosa* was eliminated from three of the five tiers it occupied in 1981, remaining only in tiers 2 and 3. Only *Salix nigra* and *Diospyros virginiana* still had some survivors in the upper four tiers; no species remained in tier 5. Despite the survival of four of the six species, cover values were extremely low in all cases, and the condition of remaining plants was so poor that overwinter survival appeared unlikely.

PART IV: DISCUSSION

59. The inundation trials at Lake Texoma showed that shoreline revegetation efforts must involve evaluation of a variety of factors. The ability of the tested species to survive and grow under experimental conditions varied with hydrologic characteristics (depth, duration, and timing of inundation), climatic variables (seasonal distribution of rainfall and winter conditions), and species characteristics (flood and drought tolerance, height). No single species was well adapted to withstand all of the stresses imposed, but several showed promise for application in particular circumstances.

60. All of the species tested were selected for evaluation based on demonstrated ability to tolerate growing season flooding, as indicated in various published studies. Differential pretreatment survival occurred and influenced the eventual overall success of each species, but whether this "transplant success" factor is species specific or is related to planting stock condition cannot be evaluated in most cases. Soil conditions undoubtedly were more favorable to some species than to others, but this, too, is beyond the scope of the study. Despite the presence of these potentially confounding factors, the Lake Texoma study produced a great deal of information regarding the limitations and potential of the tested species for shoreline revegetation applications.

Herbaceous Species

61. Several species (*Buchloe dactyloides*, *Tripsacum dactyloides*, and *Paspalum floridanum*) did not demonstrate sufficient flood tolerance to merit consideration in most potential reservoir shoreline revegetation applications. While all three persisted and performed very well in tiers flooded less than 4 weeks annually, they declined sharply or were eliminated where flood durations exceeded 4 weeks. The extended inundation in 1982 totally eliminated all individuals of these species. In operational applications, occasional extreme conditions must be

anticipated; therefore, the failure of these species in 1982 indicates they are inappropriate even for the highest sections of the fluctuation zone.

62. Of the remaining species, all survived the 1982 shoreline inundation to some extent (with the possible exception of *Arundo donax*), and all showed some ability to survive at least 4 weeks of annual flooding in previous years. Performance varied among species; however, *Panicum hemitomon* was unable to achieve more than 20-percent coverage on any tiers except those flooded for 2 weeks or less, where coverage ranged from 40 to 60 percent in 1980 and 1981. *Phragmites australis* survived in all tiers throughout the study, but coverage never exceeded 40 percent and had declined to under 20 percent on all tiers by the end of 1981. Similarly, *Cyperus esculentus* persisted through periods of inundation lasting 6 weeks (more in 1982), but coverage remained less than 30 percent on all tiers throughout the study. None of these three species showed sufficient ability to expand from transplants to provide rapid coverage and stabilization of a shoreline site. However, their persistence through prolonged periods of flooding suggests they may be appropriate where mixtures of various species will be introduced to a seasonally inundated environment. *Panicum hemitomon* may be appropriate for single-species plantings in the upper fluctuation zone where flooding is limited to 2 weeks or less.

63. *Panicum obtusum* and *Spartina pectinata* performed well overall, but were somewhat erratic from year to year and between sites and tiers. *Panicum obtusum* on the shoreline achieved better than 50-percent cover only in the third tier (4 weeks of flooding in 1981) but performed best in the top tier (no flooding) at the control pool. These results suggest that this species may be sensitive more to flood depth than duration; that is, where it is totally immersed it does poorly, but where it protrudes above the surface it tolerates considerable flooding. *Spartina pectinata* had better than 80-percent coverage in all control pool tiers by the end of 1981, but exceeded 50-percent coverage only in those shoreline tiers receiving 4-6 weeks of inundation in 1981. Both of these species appear suited for shoreline revegetation projects,

but it appears that *Spartina* may be most appropriate for more deeply flooded sites while *Panicum obtusum* may be a good choice for moderately flooded sites that may be droughty for parts of the growing season.

64. Two species appear well suited for most fluctuation zone applications represented by the experimental conditions of this study. *Panicum virgatum* and *Arundo donax* both maintained better than 50-percent cover (often 100 percent) on all but the lowest shoreline tier in 1981, indicating they had no difficulty surviving and actively growing with 6-7 weeks of flooding. *Panicum virgatum* was evidently eliminated by 20 weeks of flooding in 1979, but survived well through the extended inundation of 1982. *Arundo donax* was not eliminated from tier 5 by the 1979 flooding; thus, it is assumed here that its apparent elimination in 1982 was probably misleading. As noted earlier, the root structure and past performance of this species suggest it is very likely to recover fully in subsequent growing seasons, even after it appears to have been devastated by floodwaters.

65. The suitability rankings given above illustrate the importance of height as an element of flood tolerance among these species. Once the apparently intolerant species are eliminated from consideration, the ability of the remaining species to keep some part of their stems above water level seems to be related to their overall performance. The two tallest species (*Arundo donax* and *Panicum virgatum*) were clearly the best and most consistent performers across a broad range of flooding conditions at both sites.

Woody Species

66. The height factor discussed above is not directly applicable to the woody species tested, as all are capable of matching or exceeding all of the herbaceous species with respect to potential height. However, the size of the original transplants and subsequent growth rates may be of importance in determining the likelihood of total transplant immersion in the first few seasons of growth. Since transplant size was fairly consistent among species in this study, it is assumed all species

were given a fair test. However, if any woody species are to be used in revegetation efforts, the possibility of using the tallest available transplants should be considered.

67. Of the woody species, *Sapindus drummondii* and *Betula nigra* performed very poorly, with low initial survival and generally declining performance through the 2 years of study. Neither species showed any survival after the 1982 season, and they appear to be inappropriate for reservoir shoreline applications. *Quercus macrocarpa* performed somewhat better, but appears to be limited to sites where flooding durations are fairly short (2-3 weeks annually).

68. *Diospyros virginiana, Salix nigra*, and *Amorpha fruticosa* all persisted in all five tiers at the end of 1981 and showed better than 40-percent survival in one or more of those tiers. All of these species also survived the 1982 inundation in the middle tiers. *Diospyros* and *Amorpha* showed distinctly better growth where flooding did not exceed 3 weeks in 1980 and 1981. *Salix nigra* was by far the most successful species in terms of coverage, and attained its greatest coverage in the most-inundated tier (but was completely eliminated from that tier in 1982). These three species appear to have potential for use in transplant programs, but they may be totally eliminated by extreme conditions.

PART V: SUMMARY

69. From 1979 through 1981, field trials were conducted at Lake Texoma to determine the suitability of selected plant species for shoreline revegetation projects. Of 16 species tested, three showed very good potential, four demonstrated limited usefulness, and four merit consideration only in certain specific situations. The remaining five species were judged unsuitable for most shoreline revegetation applications. Table 5 presents the maximum annual flood duration under which each successful species survived satisfactorily. While flood duration is considered the primary determinant of species success, other factors (water depth, soil condition) also may influence the success of any transplanting program. Where maximum coverage is required to minimize erosion and improve fish and wildlife habitat quality, a mixture of various species introduced across a range of inundation conditions is likely to produce the most satisfactory results.

Table 5

Species Flood Tolerances

Species	Maximum Annual Flood Tolerance weeks
Herbaceous	
Arundo donax	7
Panicum virgatum	7
Cyperus esculentus	6
Phragmites australis	6
Spartina pectinata	6
Panicum obtusum	4
Panicum hemitomon	2
Woody	
Salix nigra	6
Amorpha fruticosa	3
Diospyros virginiana	3
Quercus macrocarpa	2

APPENDIX A: SCIENTIFIC AND COMMON PLANT NAMES USED IN TEXT

Scientific Name	Common Name
Agropyron smithii	western wheatgrass
Amorpha fruticosa	lead plant
Andropogon glomeratus	bushy beardgrass
Arundinaria gigantea	giant cane
Arundo donax	giant reed
Betula nigra	river birch
Buchloe dactyloides	buffalo grass
Cyperus esculentus	yellow nutgrass
Diospyros virginiana	persimmon
Panicum hemitomon	maidencane
Panicum obtusum	vine mesquite
Panicum virgatum	kanlow switchgrass
Paspalum floridanum	paspalum
Phragmites australis	common reed
Quercus macrocarpa	bur oak
Quercus marilandica	blackjack oak
Quercus stellata	post oak
Salix nigra	black willow
Salix spp.	willow
Sapindus drummondii	soapberry
Spartina pectinata	prairie cordgrass
Tripsacum dactyloides	eastern gamagrass

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